diamond-shaped, with the lower part of the diamond more obtuse-angled than the upper; from the lower angle of the diamond there descends what is probably a fairly wide straight-sided slit, but its edges seem always more or less broken away; in the best-preserved specimens two long and very slender feeler-like processes project into the aperture from either side of the upper end of the slit; when all the fragile part has been broken away the aperture is enlarged into a fairly symmetrical diamond.

This species is very strongly associated with the subzone of *Offaster pillula* (in the zone of *Actinocamax quadratus*) and the immediate neighbourhood of that horizon, occurring with great constancy, though always scarce. Otherwise I have only found it in the *Uintacrinus* band in Hampshire and Kent and in the *Marsupites* band in Hampshire, and then only most exceptionally.

EXPLANATION OF PLATE VII.

FIG. 1. *Rhagasostoma Sussexiense*. Part of a branch. × 12.
,, 2. Ditto. Another part of the same branch. × 21.
,, 3. Ditto. The same specially lighted to show up the outlines of the zoœcia and avicularia.
,, 4. Ditto. Part of another branch. × 12.
,, 5. Ditto. Ditto. × 12.
,, 6. Ditto. Cross section through a branch. × 12.
,, 7. *R. palpigerum*. A fragment of a large zoarium from the *Uintacrinus* band, Margate. Nat. size.
,, 8. Ditto. Part of the same. × 12.
,, 9. Ditto. Ditto. × 21.
,, 10. Ditto. Part of a branch from the subzone of *Offaster pillula*, Seaford. × 12.

(*To be continued.*)

II.—The Classification of the Rocks of the Western Australian Goldfields.

By J. Allan Thomson, B.A., B.Sc., F.G.S.

Contents.

I. Objects of this Paper.
II. Difficulties of Field Geology in Western Australia.
III. General Statement of the Problem, and Discussion of Previous Literature.
IV. Results of the writer's Petrographical Studies.
V. Principles of Classification.
VI. Suggested Classification.
VII. Detailed Petrographical Studies.

I. Objects of this Paper.

THANKS to the descriptions published by visiting mining engineers and the more detailed work of the Geological Survey of the State, the general geological features of those parts of Western Australia in which mining is carried on are now well known. A surprising degree of uniformity of geological structure and mode of gold occurrence is revealed over an extent of country unparalleled elsewhere

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in the world. And yet it is safe to assume that to the casual reader who has not visited the country the above publications present little else than a mass of bewildering detail.

"For reasons which can be readily understood, geological inquiry in Western Australia has up to the present consisted chiefly of a series of unconnected observations to the co-ordination of which we must look to the future."[1]

One reason for this, as outlined below, is the difficulty of field geology. A more important reason is the poor measure of comparative petrological study hitherto attempted, and the failure to use those principles of classification that have been worked out in areas of crystalline schists in Europe and America. The object of this paper is to give the main results obtained by the writer's petrological studies and to put forward as a working hypothesis a classification of the rocks which will serve as an introduction to a detailed discussion of each group in subsequent papers.

II. Difficulties of Field Geology in Western Australia.

The greater part of the State possesses an arid, if not a desert, climate, and shows, in consequence, surface features very different from those familiar in more humid regions. The most striking of these is the poor development of drainage systems in the whole region south and east of the Murchison River. On most maps there are no rivers shown within this area except in the immediate coastal districts, but large and small lakes are depicted in great profusion.[2] These lakes on inspection prove to be for the most part mere sandy depressions almost devoid of water except for a few weeks after a downpour of rain, and at other times containing only isolated pools of saline water. They are not, however, disconnected basins, for they pass at each end into dry valleys, and are clearly relicts of a former drainage system. Topographical maps of the heart of the country do not exist, so that it is at present impossible to reconstruct the earlier system and show how the lakes are connected. So flat are the present valley bottoms that it is difficult at times to say which way the present drainage runs.

The general surface of the country is remarkably monotonous. Low ridges and valleys follow one another like the waves of the sea. The valleys are rarely V-shaped or gorge-like, and most often show curves approaching those of the vertical section of a saucer. Only rarely does a dome-shaped mountain rise above the general level of the plateau.

There is a large body of evidence to show that the present surface has originated by the filling in of the valleys from one much more deeply dissected. Not only is this suggested everywhere by the cross-sections of the valleys and the alignment of the lake-basins, but it is proved in many localities by the mining of deep leads to some hundreds of feet below the surface of the present valley bottoms.

[1] A. Gibb Maitland, Ann. Rep. Geol. Surv. Western Australia for 1910, Perth, 1911, p. 12.
[2] Cf. H. P. Woodward, "The Dry Lakes of Western Australia": Geol. Mag., Dec. IV, Vol. V, p. 363, 1897.

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(e.g. Kanowna). The material filling the valleys is not, however, all or mostly of an alluvial nature. The sands which cover the lake-beds are largely wind-blown, and the same is true for much of the coarser material in the upper parts of the valleys. The whole area is swept by strong cyclonic winds, which convey the material broken by the usual agencies of desert erosion into the nearest hollows, while the finer sand is driven on to the lowest depressions, the lake-beds.

The arid climate has influenced the surface features in yet another way. The ground water level is deeper than is usual in more humid regions, and consequently oxidation of the rocks has proceeded to greater depths. This is especially the case in heavily mineralized belts, where the production of sulphuric acid from the sulphides has given the descending waters stronger powers of attack. The result is the rotting away of large bodies of rock and an increased efficacy of wind erosion. Side by side with the destruction of the solid rock has gone on a reconstruction of surface deposits of various kinds—laterites, surface quartzites, 'cement,' and 'cement gravel'. The laterites are predominatingly aluminous where resting on granite or gneiss, and ferruginous where resting on basic rocks. Owing to their hard nature, they now form the caps of many of the smaller hills and ridges. The 'cement' consists of oxidized rock fragments bound together by a calcareous matrix. The 'cement gravel' consists of rounded or ellipsoidal balls of reddish-white material, which when broken shows a concentric structure. It appears to consist mainly of calcite, but whether the balls have formed by accretion or by replacement is not quite certain. The 'cement gravel' is equally abundant on the sides of the ridges and in the valleys.

In consequence of the large areas occupied by the clastic materials filling the valleys, the deep-going oxidation of many of the rocks, and the widespread covering of surface deposits, the opportunities of examining the solid rocks are greatly curtailed. The rock, if it may be called rock that is at the same time hardest and least subject to oxidation, is jasper, and this forms the summits of many of the ridges. Other ridges are formed of practically unoxidized amphibolites or serpentines. Geological mapping is only possible by the acquisition of a local knowledge of the nature of the oxidized products of known rocks, and by inference from the surface deposits and the plant œcology. The study of rock contacts is seldom possible. Under all the circumstances it is no matter of surprise to find that our knowledge is practically confined to the immediate vicinity of the goldfields, where the underlying rocks are exposed by mining and prospecting operations.

III. General Statement of the Problem, and Discussion of Previous Literature.

With few exceptions the gold-bearing deposits are enclosed within basic schistose rocks, which are foliated in a general north-south direction and are highly inclined. The direction of foliation varies from N.E.–S.W. to N.W.–S.E. The schistose rocks alternate with, or enclose, lenticles of more massive rocks of similar composition.

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In some districts there appear also to be sedimentary rocks associated with them. The whole complex is generally referred to as the 'Auriferous Series'. All these rocks occur in relatively narrow belts, separated by wider belts of granite and gneissic rocks, which when foliated possess the same general direction of foliation. All these belts possess a trend, so far as known, parallel to the foliation. Within the auriferous belts in almost every goldfield there are elongate lenticular bands of ferruginous and non-ferruginous jaspers and graphitic schists which also follow the same lines of trend. In most fields there are relatively unaltered intrusive rocks of various natures, viz. felsites, porphyries, porphyrites, and more basic rocks, which in some cases run parallel to, and in others cross, the direction of foliation.

A peculiar feature of many of the schistose rocks of the State is that when cut in depth by mining operations they are frequently stated to be quite massive.[1] In some cases this statement may be based on a faulty correlation: the shafts may pass through a band of schist into an unsheared phacoid of massive rock of similar constitution to the schists. It is, however, undoubtedly the case that many rocks which are apparently quite massive when mined, develop a latent schistosity after some years' exposure in mine dumps, and since this is so it is also reasonable to admit that this latent schistosity may be developed in the weathered parts near the surface. Dykes of sericite schist not unfrequently pass in depth into massive porphyries.

H. P. Woodward[2] in 1895[3] relegated these rocks to the Archæan, and divided them into granites, gneisses, and schists. He described the existence of six great belts crossing the country from sea to sea in a north–south direction. Commencing from the west coast near Perth, these belts are consecutively 'crystalline', 'crystalline', granite, western auriferous belt, granite, and eastern auriferous belt. The relationship of these belts to one another is not clearly indicated, but apparently he recognized that the granites are intrusive into the auriferous series, for he mentions that the western auriferous belt is broken and faulted by granite and diorite dykes. Subsequent observations have been very largely confined to the auriferous belts, and do not seem to have greatly modified Woodward's statement. A seventh belt of gneiss-granite has, however, been recognized on the eastern boundary of the Coolgardie–Kalgoorlie belt by Gibson.[4] A map of the State embodying the recently acquired knowledge is a great desideratum.

Much of the earlier literature relates to the Coolgardie Goldfield and its immediate surroundings, but is, unfortunately, of a very vague character. Coolgardie is situated on the contact zone between a granite on the west intrusive into the auriferous series in the east.

[1] Bull. xxii, pp. 15, 16, 1906. In this and subsequent references 'Bull.' stands for Bulletin of the Geological Survey of Western Australia.

[2] *Mining Handbook to the Colony of Western Australia*, Perth, by Authority, 1895, pp. 37, 38.

[3] The writer has not had access to Government publications prior to 1894.

[4] C. G. Gibson, Bull. xxiv, pp. 29, 30, 1906, and Bull. xxxvii, p. 23, 1909.

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The granite along its margin is distinctly gneissose, while the result of contact alteration has been to reconstitute the basic rocks into well-foliated schists. Göczel[1] and many other observers supposed the granite to be a basal Archæan series on which the younger auriferous series was deposited as lavas and tuffs. Chewings[2] in 1896 and Blatchford[3] in 1899 clearly recognized the intrusive nature of the granite, and since that time granites intrusive into the auriferous series have been recognized over the whole length and breadth of the State. But at the same time the distinction between these granites and older gneisses has not always been held in view. Each of the main rock-series will now be briefly reviewed.

Gneisses.—The gneisses have not hitherto received any petrographical or chemical study. Their presence is noted in the Northampton Lead and Copper Field by A. Gibb Maitland.[4] The rocks are briefly described as "granites, gneisses, mica schists and quartz schists, etc., intersected by veins and masses of pegmatite".

"Sheeted zones of micaceous and garnetiferous schist and of garnetiferous gneiss stand out in bold relief with a general north-west and south-east trend." Maitland at one time believed the oldest rocks of the Pilbara District to be "granites and gneisses which form the platform upon which the oldest formations were laid down, and which everywhere underlie the plain extending from Port Hedland to Doolena Gorge on the Shaw River".[5] In a later publication, however, he concludes that the granite and gneisses are everywhere intrusive into the greenstones and associated beds,[6] so that it is doubtful whether any basal gneisses outcrop in the Pilbara District.

H. P. Woodward has described the occurrence of a series of gneisses, mica-schists, sericite schists, and quartzites in the Menzies Goldfield, but does not indicate very clearly whether he regards these rocks as older than, contemporaneous with, or younger than the amphibolites of the auriferous series.[7]

The Greenbushes Tinfield appears to be the chief mining area where pre-granitic gneisses and greenstones exist side by side, but again their relationship to one another is not clearly indicated. Woodward[8] describes the 'Crystalline Series' as consisting of gneisses merging in places into dark-coloured mica-schists, and intersected by dykes of albite-pegmatite, and basic rocks consisting of highly weathered hornblende and mica-schists, penetrated by dykes of highly foliated granite which are in turn penetrated by pegmatites. Dykes of bronzite-diabase intersect both gneisses and basic schists, but their relationship to the pegmatites is doubtful.

Numerous references to gneiss and gneissic granites in the Gascoyne, Ashburton, and West Pilbara Goldfields are made by Maitland,[9] but none of these are sufficiently definite for our present purpose. It

[1] G. Göczel, Interim Report, Dept. of Mines, W.A., for half-year ending June 30, 1894, pp. 18–23, Perth, 1894.

[2] C. Chewings, Proc. Roy. Col. Inst., London, vol. xxvii, pp. 263–371, 1896.

[3] Torrington Blatchford, Bull. iii, p. 20, 1899.

[4] Bull. ix, p. 9, 1903.

[5] Bull. xv, p. 10, 1904.

[6] Bull. xxiii, pp. 79, 80, 1906.

[7] Bull. xxii, pp. 14–16, 1906.

[8] Bull. xxxii, pp. 26–30, 1908.

[9] Bull. xxxiii, 1909.

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can hardly be doubted, however, from the numerous references to extensive tracts of gneiss and gneissic granites outside the actual mining fields of the State that there is a fundamental system of Archæan gneisses similar to that of most other parts of the world, and probably of earlier age than the auriferous series. Seeing that so many of the granites are known to be intrusive into the auriferous series, it is remarkable that the distinction between newer granites and older gneisses has not been more clearly held in view by the officers of the Geological Survey of the State,[1] particularly as the former are intimately connected with the gold occurrences, and the latter, except where intruded by later granites, are free of all economic minerals.

The Auriferous Series.—The rocks of this series are wonderfully uniform both in original petrological nature and in their present state of alteration over the whole State, and it is a perfectly justifiable assumption to regard them as of similar age. A large series of reliable chemical analyses has been made of them, but the accompanying petrological study has been very meagre, and vitiated by a lack of comparative studies. In most of the Bulletins of the Geological Survey it is briefly stated that the rocks are of the general type common to the goldfields of the State, and they are divided into massive and foliated varieties, and again into coarse-grained and fine-grained. Excellent petrological studies were carried out by Vogelsang[2] in 1897, and he showed that some at least of the amphibolites had originated from 'diabases'. Yet in spite of this and of the numerous analyses, the opinion is still occasionally put forward that the series may be of sedimentary origin. Vogelsang has, however, generally been followed by Simpson and Gibson, who have described more massive varieties as epidiorite, diorite, and amphibolites after 'diabase' and pyroxenite, and chloritic and sideritic rocks derived from amphibolite. No attempt has been made, except in Kalgoorlie, to map the various members of the series separately. It is greatly to be hoped, now that a petrologist has been added to the staff of the survey, that this will be attempted in all the principal goldfields, for otherwise the geological maps produced are practically valueless to the mining community.

The banded jaspers or 'ferruginous quartzites' which penetrate the amphibolites and hornblende schists of the auriferous series are generally admitted to be of the nature of lode formations or bands of highly replaced rocks. That they are anterior to the main deposition of the gold is also generally recognized.

The Granites and accompanying Dykes.—The granites generally form the boundaries of the auriferous series, and have seldom, therefore, been completely mapped. The smaller intrusions appear to be boss-shaped, while the larger ones are aligned in N.–S. bands. At the junction the auriferous series is almost invariably represented by well-foliated hornblende schists, whose foliation is parallel to the line

[1] Witness the practice of depicting granites known to be intrusive as 'Gn.' on the geological maps.

[2] K. Schneisser and K. Vogelsang, *Die Goldfelder Australasiens.* English translation, *The Goldfields of Australasia*, H. Louis, London, 1898.

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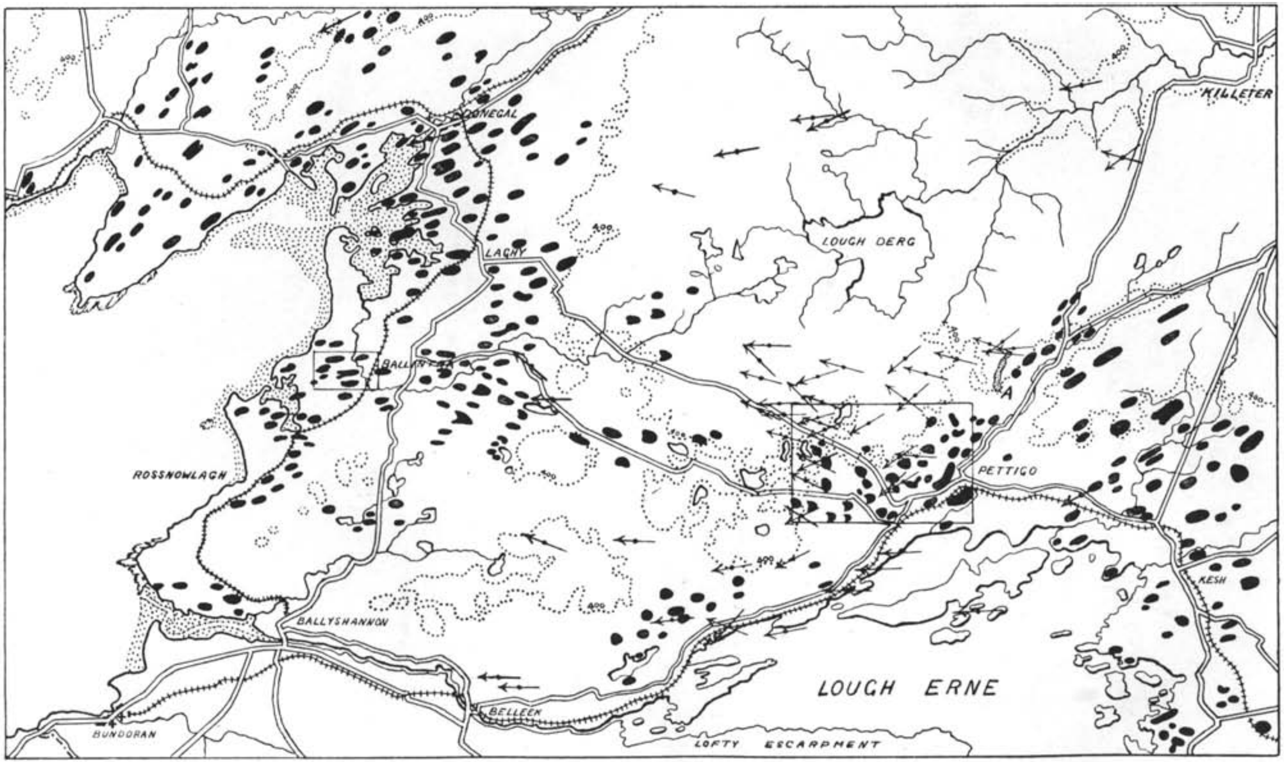

Map of South Donegal showing the distribution of Drumlins.

of junction. That the granite has exercised a distinct contact action on the auriferous series is not generally recognized. The accompanying dykes are sometimes considered to be a later series, where they cut both the granites and the hornblende schists, but this, of course, is not a necessary assumption, for practically all granites are cut by dykes belonging to the same general series of intrusions. The granites have received a little petrographical treatment, but no classification of them into groups has been attempted. The accompanying dykes consist of fine-grained granite, granite porphyry, quartz porphyry, and 'felsite'. For the most part they follow the direction of foliation or are slightly oblique to it.

Granites of more than one age are occasionally recognized in the same field. Thus, near Mt. Percy in the Edjudina District, North Coolgardie Goldfield, Maitland describes a foliated granite (apparently intrusive into greenstone) and a later unfoliated granite.[1] In the North Murchison Goldfield, also, Gibson considers the granites of two ages, a younger undoubtedly newer than the greenstones, and an older of doubtful age.[2] In the Stannum Group of the Woodgina Tinfield, Pilbara Goldfield, Maitland recognizes an area of intrusive porphyry which is of later date than the greenstones and older than the granite and pegmatite veins.[3]

The close association between the intrusion of the granites and the deposition of the gold has been frequently, if not very clearly, indicated. The majority of the smaller goldfields are situated within the contact aureole of the granites, and many reefs are directly associated with dykes of 'felsite'. In a few fields the gold deposits are found within the granite itself. In other cases it is found that the deposits are intersected by dykes of acid rock.[4] The close association of tin and tantalum with albite-pegmatite is very clear.

(*To be concluded in our next Number.*)

III.—The Drumlin Topography of South Donegal.

By W. B. Wright, B.A., F.G.S.

PLATES VIII AND IX.

(The observations relating to the Pettigo area are communicated with the permission of the Director of the Geological Survey of Ireland.)

Most people who have lived in strongly glaciated countries are familiar with the topographic features known as drumlins. They are more or less elongated hills of boulder-clay with their long axes parallel to the direction of ice-motion. The literature dealing with them is extensive, but for the most part rather unsatisfactory. Their mode of formation is entirely a matter of speculation and is likely to remain so. There is every reason to believe they are deep-seated products of the ice, so that observation of the process in modern ice-sheets is impossible. The only available means of getting at the

[1] Bull. xi, p. 30, 1903.
[2] Bull. xiv, p. 13, 1904.
[3] Bull. xxiii, p. 61, 1906.
[4] Gibson, Bull. xii, p. 11, 1904.

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